

The Divergent Dynamics of Economic Growth

*Studies in Adaptive Economizing, Technological
Change, and Economic Development*

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Contents

<i>Preface</i>	<i>page ix</i>
<i>Acknowledgments and Comments</i>	<i>xiii</i>
1 The Adaptive, Evolutionary Theory of Divergent Economic Growth	1
PART ONE. GLOBAL TRENDS AND ADAPTIVE ECONOMICS	
2 Global Trends, World Models, and Human Adaptation	21
3 Adaptive Economic Theory and Modeling	36
PART TWO. TECHNOLOGICAL CHANGE IN AGRICULTURE AND INDUSTRY	
4 The Economics of Technological Change and the Demise of the Sharecropper	59
5 Economic Development as an Adaptive Process: A Green Revolution Case Study <i>Richard H. Day and Inderjit Singh</i>	79
6 Industrial Development and Technological Change <i>Richard H. Day, Masatoshi Abe, Jon Nelson, William K. Tabb, and Che Tsao</i>	97
7 An Adaptive Economizing Analysis of Chinese Enterprises Under Alternative Reform Regimes <i>Richard H. Day, Zhigang Wang, and Gang Zou</i>	115
PART THREE. EPOCHAL DEVELOPMENT	
8 Economic Development and Migration <i>Richard H. Day and Yiu-Kwan Fan</i>	141

9	Instability in the Transition from Manorialism: A Classical Analysis	158
10	Do Economies Diverge? Economic Development in the Very Long Run <i>Richard H. Day and Oleg Pavlov</i>	178
PART FOUR. TOWARD A GENERAL THEORY OF DEVELOPMENT		
11	Economics Far from Equilibrium	203
12	The Dialectical Republic: Toward a General Theory of the Coevolution of Market and State	221
	<i>Index</i>	237

ONE

The Adaptive, Evolutionary Theory of Divergent Economic Growth

In law eternal it lies decreed
that naught from change is ever freed.
Boethius, *The Consolation of
Philosophy*

1.1 Reconsidering Economic Theory

Informing the central message of Adam Smith is the recognition that no one understands everything but private individuals in the pursuit of self-interest can contribute to the advantage of others even though they may not intend to do so and may not concern themselves with the economy as a whole. A system of private property and market competition is needed to make this possible: Private property empowers the individual and creates scope for discretion in coping with local situations, that are what each individual knows best; market competition provides incentives for individuals to expand their potential and exercise effective choices. In setting forth this vision of the competitive process, Smith and his followers explicitly recognized that producers and consumers adapt their behavior to price signals that reflect imbalances in supply and demand.

A century after Smith, Léon Walras formalized the idea of a balance or equilibrium in supply and demand and specified two complementary mechanisms of out-of-equilibrium adjustment: consumers' *tâtonnement* (literally, "groping in the dark"), involving price adjustments in response to

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discrepancies in supply and demand, and producers' *tâtonnement*, involving quantity adjustments in response to profit opportunities. He emphasized that such a system of dynamic relationships would not converge to a general equilibrium but would oscillate around one, sometimes approaching a steady state (like a "glassy sea") and sometimes exhibiting more or less turbulent fluctuations (like an "ocean storm").

Thus, from the beginning of the discipline's "modern" era, two complementary streams of thinking have flowed through the domain of economic theory – one characterizing and deriving properties of economic equilibrium, the other characterizing and deriving properties of disequilibrium. Both are found running through all the great classical and neoclassical founding fathers and in the great economists of the twentieth century, including (among many others) Wicksell, Keynes, Schumpeter, Hicks, and Hayek.

Equilibrium concepts are sometimes argued to be most relevant for studying the "long run," that is, for identifying and analyzing the state toward which an economy must presumably be heading. But even a cursory glance at history tells us that human development has approximated an equilibrium state only occasionally – and then only temporarily. Rather, at any one time, history is more meaningfully described as a process of moving away from an equilibrium, and any equilibrium toward which it may be moving at the moment is itself changing with no possibility of ever catching up. If this is true, then it is remarkable that, during the last quarter century, economists – especially growth theorists – have come increasingly to rely exclusively on the concepts of economic equilibrium. It seems to me high time to reverse this disciplinary trend. Accordingly, the essays in this volume are offered in the hope of reinstating a more realistic approach that better answers the questions of if, why, and how economies develop?

But suppose one already has an adequate descriptive history of what has happened. Why, once that knowledge is acquired, does one need a theory or model to characterize it? Just what does a theoretical model add to the story that the facts already tell? First of all, the model itself is not a descriptive history but a hypothetical framework of cause and effect. This framework characterizes specific relationships among the variables that tell the development story. Second, if the causal framework produces data that correspond to historical facts, then we are permitted to entertain the possibility that we understand why those facts came about as they did and not some other way. Third, with this kind of understanding, useful clues about the future may be inferred. Of course, the model variables and the causal relationships merely

approximate their real-world counterparts; moreover, the model-generated histories are not expected to recreate all the details of place or time. But we do demand that the histories mimic the real-world process in some of its most salient features.

1.2 An Overview of the Essays

The essays collected in this volume all deal one way or another with three intertwining themes.

1. New technology and economizing behavior induce vast changes in productivity, resource allocation, and labor utilization.
2. These changes have made possible an explosion in human numbers, drastic changes in resource utilization, and massive relocation of people from rural regions to concentrated urban centers.
3. To understand these developments scientific economic theory needs to incorporate concepts of adaptive, economizing, and structural evolution.

The reorientation of economics around these themes does not require abandoning economic optimization and equilibrium theory, for that theory makes possible a rigorous definition of what perfect coordination is and what practical and theoretical problems arise when coordination is not perfect. For this reason, equilibrium and disequilibrium are dual theoretical concepts; that is, one implies the meaningfulness of the other. The former describes how economies would function if everyone's actions were perfectly coordinated and no one had an incentive to modify the distribution of wealth or his or her behavior; the latter characterizes how economies really function.

The second chapter emphasizes the global context of human development. From that point of view – from the world as a whole and the history of our species over its entire span – economic growth is an explosive process. It involves increasing population, intensifying resource utilization, frequent restructuring of production, redistribution of populations, and changes in consumption and behavioral patterns. For the world as a whole, and at the scale of the lifetime of the earth, population, production, and resource utilization form spikes. Within these spikes, individual cultures and political units emerge, each depending on some dominant way of life that flourish, decline, and disappear. On the scale of the last two centuries, the period accounting for almost the entire “height” of the human trajectory, overlapping waves of individual technologies appear with successive waves rising far above their predecessors before they too fall as new waves supersede

them. From this very long run perspective, economic development is a counterpoint of growth and decay with the pace and magnitude of change accelerating.

Chapter 3 reviews the fundamental theoretical and methodological concepts that will be exploited in the remaining essays for understanding the development story. These concepts are based on empirical characteristics of actual economizing activity. A general analytical framework is outlined and examples of adaptive economic models are briefly reviewed – in particular the class of “recursive programming” or “adaptive economizing” models.

The essays in Part II deal with microeconomic transformations involving rapid technological change in specific, narrowly defined agriculture regions and industrial sectors. These transformations provide coherent economic histories of specific settings of time and place. From the theoretical point of view they constitute tests of adaptive economizing theory, of the recursive programming methodology, and the role of multiphase dynamics in describing structural transitions. The implications extend far beyond the specific circumstances investigated. Thus, the dynamic microeconomic theory, properly constituted to represent the realities of human decision making and the strategic details of production technologies, provides a coherent and substantially correct explanation of the macroeconomic effects of the forces at work at the microeconomic level and how the social landscape of a region or industry is transformed within a fraction of a century.

The essays in Part III are concerned with the macroeconomic effects of accumulating change within a national economy or the entire world over long periods. Methodologically, it involves a progression from the microeconomic studies of individual, specialized sectors to the study of development on a grand scale over a century, several centuries, or over many millennia. Chapter 8 describes a hypothetical economy using a multisector model that generates capital accumulation and technological change in industry and agriculture. The corollary is the industrialization of agriculture and the urbanization of population – a process that occurs, once started, primarily within one generation. It mimics in macroeconomic terms the transition process described in microeconomic terms in Part II that has taken place already or is well under way in virtually every region of the world.

Chapter 9 considers economic growth and the switching of economic distribution systems during the transition to market-oriented production in the manorial economies of the middle ages. At this level of theorizing, inferences are entirely qualitative. Nonetheless, the analysis shows how growth can lead an economy away from a given system and into another with very different economic characteristics. This exercise also explains how

noneconomic events – in this case the early fourteenth-century plague – can alter the chain of events and bring about a temporary restoration of an earlier regime.

From the long run of three quarters of a century or of several centuries in Chapter 9, Chapter 10 is concerned with the very long run, that is, the evolution of the world through the great socioeconomic epochs from hunting and food collecting through settled agriculture, the city-state, trading civilizations, the nation-state, and into the present global-information-based economy. The analysis suggests that the global forces operating over the very long run have implications for the short run – in terms of imminent, potentially catastrophic problems and the crucial focal points for solving them.

Economic theory provides a way to think about and understand economic aspects of experience. On the basis of that understanding, it provides a rational way to influence actions. If mental images of theory do not adequately reflect what is really “out there,” then action may be ineffective or counterproductive. Survival may be jeopardized. The research described in Parts II and III led me very early on to see economic optimizing and equilibrium theory (by themselves) as inadequate mental images of the real economic world. The individual case studies suggest a general, unified system of thought that provides an enhanced basis for thinking more broadly about economics, society, and human development. That unified system of thought is the subject of Part IV, which concerns the foundations for a general theory of economy and state based on principles of adaptation, multiphase dynamics, and evolution.

Chapter 11 describes the relationship of complex multiphase dynamics to concepts of punctuated equilibrium, endogenously generated structural change, and economic evolution, illustrating the general concepts using individual studies of Parts II and III as examples. Chapter 12 explains how cognitive limits and adaptive economizing behavior prevent perfect coordination among the parts of the economy; how the lack of coordination requires intermediating mechanisms of exchange and why conflict arises that requires institutions of civil order; how the creative faculty of mind perturbs the existing system, thus providing new opportunities and new solutions, which often generate unforeseen consequences; how the democratic system provides recourse to market and governmental coordination failures; and how, in response, policies that introduce new opportunities and constraints are innovated. Such new constraints and opportunities change the environment within which private economizing takes place. Thus, market and state coevolve.

1.3 The Recursive Programming Methodology

In the case studies of specific development periods and processes of Parts II and III, much use is made of a class of dynamic models referred to as “recursive programming” or “adaptive economizing.” The term recur means “to come up again for consideration, thought or discourse” and “to occur again after an interval.” Programming is a term used, more or less synonymously, for the constrained optimization problems that arise in many different theoretical and applied fields – especially in economics. Best economic choices or decisions are modeled mathematically in this way. Thus, recursive programming implies making “best” decisions again and again as time passes. I put best in quotes because, in line with the modes of economizing behavior, my models describe choices in a *neighborhood of current practice* based on a cautious response to estimates of future consequences using partial information and calculated for a finite, usually short, time horizon. The decision maker adapts recursively, more or less cautiously moving in the direction of what, on the basis of incomplete knowledge, seems like the “best way to go” and then reconsiders after time passes and new information has been revealed. In contrast to this usage, an important school of macroeconomic theorists uses the term “recursive methods” or “recursive models” to describe economic choices governed by a recursively applied, optimal strategy.¹ The latter is a mathematical rule that governs the decision maker’s present situation and prescribes once and for all what is the best thing to do on the assumption of perfect knowledge of all possible consequences forever.

Recursive programs involve various constraints that may or may not be effective or limitational. If they are, they have a causal impact; otherwise, they do not. Moreover, the various activities about which decisions are being made may or may not be pursued. It is the local optimizing choice that determines which activities are undertaken and which constraints are binding. The currently pursued activities and binding constraints form a “causal structure.” In the various models of this genre described nontechnically in subsequent chapters, the specific activities pursued and the specific constraints that are binding change from time to time, which is equivalent to a change in the structure of causal relationships characterizing the dynamic process over time. The period of time during which a given causal structure

¹ For the fundamental treatise, see Stokey and Lucas, 1989, *Recursive Methods in Economic Dynamics*, Cambridge: Harvard University Press. For representative recent contributions, see Cooley (ed.), 1995, *Frontiers of Business Cycle Research*, Princeton: Princeton University Press.

is effective is called a *phase*, *regime*, or *epoch*. The history of a given economic organization, sector, or economy as a whole is thus described in terms of the sequence of phases through which it passes. Structural change is modeled explicitly, and economic evolution is seen to consist of the endogenous generation of one structure after and “out of” another – in this way taking a giant step forward in the task of understanding economic development in rigorous theoretical terms.

1.4 Elements of the Argument

Before going into the individual studies, it may be useful to anticipate the basic concepts and overall theory that emerges from them.

1.4.1 Modes of Economizing Behavior

In addition to conscious comparison of alternatives, that is, rational choice, behavior in economic situations is governed by imitation, by “trial and error,” and by accidental modifications of behavior that, in effect, constitute unintended “innovations.” These, if successful, can be selected by others through imitation in the pursuit of advantage. Less successful behavior may be culled as experience accumulates. Obviously, of course, intended innovation guided by conscious design also contributes to the process, but the central point is the impossibility of acting optimally because of informational and cognitive limits and the possibility of improving performance nonetheless.

In addition to explicit or procedural optimizing, experimentation, trial and error, and imitation, I include as distinguishable (but perhaps not independent) modes of economizing following an authority, tradition, or habit, unmotivated search, and following a hunch. All of these modes – including procedural optimizing – share the characteristic that those who use them do not know and do not find out what is the best thing to do. At best, these people can only do their best as they are able to perceive or calculate it, and this may lead them to abandon optimizing behavior and engage in trial-and-error search, to imitate, to obey an authority, to repeat previous actions mindlessly, or simply to guess.²

² In his classic paper, Armen Alchian (1950) observed that [in the real world] “modes of behavior replace optimum equilibrium conditions as guiding rules of action.” I have elaborated these “modes of economizing behavior” most recently in Day (1992). Pingle (1994, 1995) has shown how these modes arise in various laboratory experiments.

1.4.2 The Problems of Disequilibrium: Suboptimality, Mediation, Instability, and Inviability

Given these fallible modes of behavior, intelligent individuals have good reason to seek knowledge. But that is costly. It takes time and other resources. And it perturbs individuals from whatever positions they are in, which in turn perturbs the entire interacting system of which they are a part. That interacting system can strike an equilibrium, if one exists, only by chance, and the chance would be vanishingly small. If an equilibrium did result, no one would know it. Further efforts to understand the situation and to improve the possibilities would perturb the system out of the equilibrium again. For this reason alone, economic systems rarely, if ever, display the characteristics of perfect coordination.³

This is an implication of bounded rationality that has not yet received adequate attention. Certainly, the neoclassical economists did not deal with these implications. Subsequent writers who emphasized realistic behavior have often been too sanguine about the market's ability to overcome the difficulties it creates through its own internal workings. After all, markets are essentially a network of firms that mediate transactions for profit and whose managers are governed by the same modes of behavior that govern producers and consumers. If producers and consumers cannot perform equilibrium miracles, how then can market mediators? Of course, they cannot. Indeed, the economy as a whole can be viewed as a vast system of simultaneous experiments undertaking trial-and-error search. It is in Eliasson's (1996) felicitous phrase, "an experimentally organized economy."

The consequence of disequilibrium is serious at all times for some and at some times for many. If the agents are not in equilibrium, then they are out of it; and if they are out of it, some people cannot do what they want or hope to do. In extreme but not infrequent situations, survival may be threatened for individuals and organizations. Some may not survive. In short, economic selection, like its biological counterpart, is cruel: it expels its participants – those who cannot compete successfully lose their chance to do so. Thus, the system evolves in a fundamental way, that is, by changing its constituent "parts." Sometimes technologies or activities, or, more generally, ways of life are abandoned. Sometimes they are individual firms or other

³ Through this discussion I have in mind a Nash equilibrium as in a Walrasian general equilibrium for a deterministic economy or in a strategy space when risk is present as, for example, defined by Hahn (1973). Note that defining an equilibrium does not establish existence.

organizations. These are impersonal components of the economy, but they are components made up of persons whose individual fortunes depend on the activities, ways of life, or organization of which they are a part. When a business firm is eliminated, the individuals involved will be forced to change in ways they never intended.

When expulsion by economic selection occurs relatively slowly and involves only a few activities and organizations at any one time, the individual consequences can be absorbed without great disruption. When expulsion occurs rapidly and involves many activities and organizations, the system as a whole begins to tremble.

1.4.3 Institutional Innovation and Government

Every now and then, economic systems are so thoroughly destabilized by disequilibrium developments that they collapse entirely, as occurred in Russia in the early part of this century, in Germany in the 1930s, and more recently in the Soviet Union. Other countries, for example Great Britain and the United States, have also experienced economic crises and periods of political turmoil. They have been more fortunate, however, having successfully avoided collapse. Their history is characterized instead by episodes of substantial change when existing market or government institutions are modified or new ones are created within the same overall conceptual structure of political and economic organization. These episodes are often followed by somewhat less dramatic periods of consolidation or partial retrenchment.

A brilliant analysis of the Anglo-American interaction of market and state is to be found in John R. Commons's no-longer-read masterpiece *Legal Foundations of Capitalism* ([1924] 1959) and in a somewhat more readable rendition edited by Kenneth Parsons titled *Collective Action* 1950. Commons's method was founded on the direct observation of market and government organizations in action, on a careful description of the origin and development of specific market and governmental institutions, and on a pointillist analysis of specific conflicts that arose among private and public agents in the process. He was able then to show in varied historical cases how specific privately organized economic activities could emerge as a result of private and public innovations as new opportunities opened up, how laws were modified or reinterpreted, and how new public agencies were created to deal with conflicts that occurred when the actions of some agents led to diminished payoffs to others.

Many of the opportunities and conflicts that trigger institutional innovations arise endogenously through the out-of-equilibrium working of the market system, as explained in the preceding section. The institutional changes then modify the economic environment of the private sector by re-defining opportunities, constraints, and potential payoffs and by providing specific new mechanisms for resolving conflict and for mediating transactions. To characterize this interaction, I refer to it as the “coevolution of market and state.” A very similar vision, also based on historical analysis, is the grand theory of Douglass North (1990).

Armen Alcián’s papers are written within this tradition. Alcián argued that, until you know how the system works, you cannot understand how it can work well, that an understanding must rest on a recognition that nonoptimizing modes of behavior need to play a central role, and that the structure of property rights and the mechanisms of market and government selection are required to explain how individual fortunes and public welfare evolve. I emphasize the coevolution of market and government because changes in one virtually always directly involve or trigger changes in the other. As Alcián puts it, “there should be an evolutionary force toward the survival of larger clusters of certain types of rights in the sanctioned concert of property rights.” He did not allude to Commons’s brilliant analysis of the evolution of property as the chief medium through which the institutions of government and market coevolve in response to conflicting economic interests, but his own contribution, along with that of Coase, was instrumental in setting off an independent, somewhat parallel line of work that has sharpened our understanding of private property and how the real economic system works.

1.4.4 The General Theory of Market and State

I now present a brief outline of the theory of the coevolution of market and state that has its foundations in the “modes of economizing behavior” and in attempts to solve the disequilibrium problems.⁴

Because the system of individuals and of market and government institutions is never in equilibrium, for those whose plans are blocked various options have to exist for economic life to go on, such as doing without, drawing from inventories, queuing, or resorting to some contingent tactic

⁴ The following summarizes the theory explicated in greater detail in Day (1987). I have produced numerous variations on this theme such as my 1992 paper.

that can “keep one going” for the time being until an alternative course of action can be identified and pursued. In short, *inconsistency forces unwanted change*.

To prevent such inconsistencies and unwanted changes, “markets” fulfill two very important functions. They intervene between agents who wish to exchange but who could not possibly expend the resources necessary to find one another. For example, when we want food, we do not seek out the farmer but take ourselves to a market (literally the “supermarket”) where what we want is available without our knowing how, by whom, or even why it was provided. Food is there because we are willing to pay the cost of mediation provided by the merchant instead of paying a greater cost of finding the goods for ourselves. Likewise, the farmer no longer sends his milk in a pony cart driven by his child to dole out ladlefuls in crockery bowls to housewives along a route through the town but delivers his goods to a buyer, wholesaler, or processor without ever knowing the path by which the milk finds its way to someone’s cereal bowl or who, indeed, will consume it. In addition to lowering the cost of exchange, markets buffer the discrepancies between demand and supply that follow from the aggregate of actions taken out of economic equilibrium and no one knows where that equilibrium is or how to get to it. Instead, they produce viability for individuals in an economy too complex to be perfectly coordinated by any individual or system, market-oriented or otherwise.

As the amounts and variety of goods have escalated, the role of market mediation has escalated until it is usual for marketing costs to exceed production costs – often by substantial margins. In principle, we could all be better off if we did not have to pay for all these people and resources expended in the marketing process – if only we could exchange costlessly in equilibrium. The resources saved could be used to produce more of the goods and services we really want; or we could enjoy more leisure. Since we cannot determine such a situation, we are better off paying the cost and giving up the idea that we could be better off without mediation. Thus it is that “markets” or, more generally, “market mechanisms” create viability. They make complex exchanges economically feasible and unwittingly coordinate individual decisions that would be inconsistent without them.

This, however, is not the whole story. Disequilibrium creates dynamic movements as producers, consumers, and mediators adjust prices and quantities in attempts to balance supply and demand. We know that these dynamic movements vary in magnitude, sometimes displaying modest fluctuations

and sometimes substantial ones, and occasionally such great imbalances arise that the system of mediation that has evolved to date cannot continue to establish interagent viability. Among the effects at such times is the expulsion of large numbers of agents from the market; that is, participation in work, management, production, and consumption under prevailing conditions is blocked for many individuals, both business people and workers. When their numbers are large enough, they constitute a potential constituency and the imbalance spills over into the political system.

Government mechanisms have evolved to regulate private activity to reduce such occurrences, to lower their private and social costs, and to restore access to the system. These innovations in government have arisen in large measure as responses to the direct or indirect pressures created by the collective actions of individuals who have discovered common economic interests during times of duress. The mechanisms of modern democracy make such innovations possible within an evolving system of institutions and laws that can be created or redirected without overthrowing the entire system of government – or, so it has worked for more than two centuries. *Democracy lowers the violence of social conflict caused by economic imbalance by providing recourse for those expelled or threatened with expulsion from the market.*

This is not to say that any given governmental device or even the whole lot of such devices has been entirely successful. Indeed, there can be little doubt that many government regulations and activities have been counter-productive, moving the economy farther from desirable states than would have been the case without them. Moreover, it is correctly argued that, left to their own devices, private individuals and enterprises can, and often do, create sufficient new opportunities by adjusting themselves to aggregate imbalances, thus eliminating or drastically reducing the problems of individual inviability that disequilibrium conditions tend to cause.

But market capitalism is, if anything, an engine of rapid change. It can produce imbalances that can overwhelm its capacity for timely self-correction. When people are expelled from the system of markets, they have recourse in the system of government. Indeed, the mere perception of the possibility of expulsion is enough to motivate government innovations to modify the system and, once it is realized that the government not only creates but can influence, control, or even eliminate markets, the pressures to substitute a government agency for a private agency can proceed far enough to stifle the beneficial effects of market competition.

Thus it is that, in their coevolution, the institutions of market and of government have multiplied and elaborated their functions, evolving ever

more complex public and private systems of mediation in response to the fluctuating imbalances among economic flows.

1.5 Remarks on the Literature

A similar interest in adaptive, evolutionary change and the methods of dynamic analysis that could be used in the theoretical study of complex dynamic processes emerged about the same time in the physical, engineering, and biological sciences as well as in the other social sciences. Many of the early works are briefly described in Chapter 3. The accumulation of all this – what has actually been a normal, if intermittent, outcome of the scientific enterprise – is sometimes described as a major paradigm shift in the way people now think about the world. Looking back, however, we can clearly see that there has been – at least since the early Greek philosophers – a stream of thought concerned with the unstable, divergent nature of life. These essays belong to that tradition.

As was made clear in the opening paragraphs and will be further explicated in later essays, the adaptive, evolutionary point of view is – so far as the discipline of economics is concerned – classical in its origin and was advanced by the greatest economists of the nineteenth and twentieth centuries. With the exception of Schumpeter and Keynes, however, it never competed on equal terms with the traditional emphasis on the ideas of individual optimality, interagent coordination (the balance of supply and demand), and social efficiency. Beginning with seminal contributions by Simon (1947), Alcián (1950), and Cooper (1951), a systematic basis for rethinking this emphasis was initiated. Further developments began to appear a few years later in the papers of Cyert and March, which were collected in their *Behavioral Theory of the Firm* (1963) and in two dissertations, my own, *Recursive Programming and Production Response* (1963), and Sidney Winter's *Economic Selection and the Theory of the Firm* (1964).

In 1974, a conference sponsored by the University of Wisconsin's Mathematics Research Center brought together several contributors who had emerged in the preceding decade, including Masanori Aoki, Jean-Pierre Aubin, Sanford Grossman, Alan Kirman, Hukukane Nikaido, and Sidney Winter. This occasion provided an opportunity to set forth my own vision. Chapter 3 is the nontechnical version of that essay. At the time, it seemed that the discipline was poised for a major reorientation. Indeed, progress has continued, and now it can be said that the general approach advocated here is a major stream of economics, although sometimes under different terminological banners such as “computational,” “learning,” “behavioral”

economics, complexity theory, or interacting agents. I will not attempt to provide a comprehensive survey of the now voluminous literature. A few selected contributions and collections, however, will indicate the extent of the ongoing work.

The volume I edited with Theodore Groves, *Adaptive Economic Models* (1975), was based on the Wisconsin conference previously mentioned.⁵ I also edited a volume with Alessandro Cigno published in 1978 devoted to the recursive programming methodology. Nelson and Winter's *An Evolutionary Theory of the Firm* came out in 1982. More or less independent lines of related work exist in the fields of adaptive games, learning in micro- and macroeconomics, models of interacting agents, and especially various "Schumpeterian models" that usually involve computer simulations. Examples of books and collections of papers include Anderson, Arrow, and Pines (1988), Hanusch (1988), Heertje and Perlman (1990), Day and Chen (1993), Hodgson (1993), Dow and Earl (1999), Dopfer (2001), Punzo (2001), and Augier and March (2002).

A considerable body of literature is based on methods taken over wholesale from altogether distinct disciplines. Thus, the "system dynamics" school originated by Forrester (1961) is derived from physical conservational principles and engineering servomechanisms, while Prigogine's ideas have built on the dynamics of open physical systems far from equilibrium, i.e., those that absorb energy from – or radiate energy to – the "outside." See Prigogine (1993), also Lorenz (1963). More recent examples include Peter Albin's use of neural nets (1998) and Holland's genetic algorithms based on random crossover and recombination of strings of ones and zeros. Dawid (1999) describes how genetic algorithms have been used to model the generation of new behavioral rules in decision-making situations. For another example, Wolfgang Weidlich (2002) has exploited the master equations of thermodynamics to develop a general theory of sociodynamics, while Jean-Pierre Aubin (1997) has reoriented the pure mathematics of differential inclusions (or set valued dynamical systems), a field which he has greatly advanced, to the modeling of evolutionary systems in general and to economics in particular.

My impression is that few of these studies are based on direct observation of economic institutions or careful empirical testing using real-world data. As a result, much of this work seems to lie as far from reality as its equilibrium counterparts. Nonetheless, one must applaud the imaginative application

⁵ The organizing committee included Jacob Marschak, Theodore Groves, and Steve Robinson.

of techniques developed in other disciplines and the resulting accretion of methods available for the study of economics. Too many examples of the successful importation of ideas from one field into another exist to discourage this practice.

My own approach evolved out of efforts to model specific development processes in particular regions and industries using direct observation and the best available data, as explained in Part II. The concept of adaptive economizing that I exploited in those studies was based on the same facts that form the basis of equilibrium economic theory: that we perceive alternative actions, that technology conditions the range of possibilities before us, that we form preferences among them, and that we try to do the best we can. But rather than assume equilibrium, I emphasized that all rational thought is conditioned by what we know about the present and past, by our hopes and expectations about the future, by our limited ability to solve the problems presented to us as life unfolds, and finally by the restraint we exercise in acting on such rational plans – restraint based not on probabilistic calculations but on the general (if not universal) advisability of caution in the face of uncertainty. In constructing these models, my collaborators and I researched the relevant trade journals concerning the technical specifications of production processes and interviewed decision makers in numerous farms and factories. Our in-depth observations and empirical results support the inference, or so it seems to me, that our approach is on the right track.

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